WESTLUND

Adiabatics of Superheated Steam

Mechanical Engineering

B. S.

1911

ADIABATICS OF SUPERHEATED STEAM

BY

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THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

MECHANICAL ENGINEERING

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

1911

UNIVERSITY OF ILLINOIS

May 29 1911

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Albert Frank Westlund

ENTITLED Adiabatics of Superheated Steam

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Mechanical Engineering.

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Acting HEAD OF DEPARTMENT OF Mechanical Engineering

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ADIABATICS OF SUPERHEATED STEAM.

I. Introduction.

Due to the difficulty of applying the formula now available for making calculations in superheated steam, it seems very desirable that there should be an easy means of making these calculations. It would seem that the properties of superheated steam as given by the tables of Professor Marks and Professor Peabody and Dr. Davis would do a great deal toward simplifying this work but they are subject to the objection that they are not based on an absolute theory.

In an investigation recently carried on by Professor Goodenough, a connected theory has been evolved by means of which the important properties of superheated steam can be calculated directly without any recourse to approximation. This theory is based on the most reliable experimental data available.

II. Theory.

The characteristic equation of superheated steam as developed in this theory is given by the following:

$$v + c = \frac{BT}{p} - (1 + ap)\frac{m}{T^n} \quad \ldots\ldots\ldots\ldots (1).$$

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

in which the constants have the following values,

$B = 86.0$ when p is in lb. per sq. ft.

$B = 0.5972$ " p " " lb. per sq. in.

$\log m = 13.67938$

$n = 5$

$c = 0.096$

$a = 0.0006$ when p is in lb. per sq. in.

The equation for entropy as developed was found to be the following:

$$s = \alpha \log_e T + \beta T - AB \log_e p - Anp\left(1 + \frac{a}{2}p\right) \frac{m}{T^{n+1}} + s_0 \quad . \; . \; . \; . \; . \; (2).$$

in which the constants have the following values,

$\alpha = 0.367$

$\beta = 0.0001$

$A = \frac{1}{777.7} = \frac{1}{J}$

$s_0 = 0.3958$

a, B, m, and n have the same values as above.

Reducing to common logarithms and substituting the above constants, equation (2) becomes

$$s = 0.8451 \log T + 0.0001\, T - 0.2547 \log p$$

$$- p(1 + 0.0003\, p) \frac{C}{T^6} - 0.3958 \quad . \; . \; . \; . \; . \; . \; . \; . \; (3).$$

in which log C = 13.64593

III. Method of Investigation.

Since the adiabatic expansion represents most nearly the actual change taking place in the cylinder of an engine or the stages of a turbine, it is perhaps the most important. It represents the ideal condition. Thus it is very necessary to have an easy method of determining the properties of superheated steam during an adiabatic expansion.

By means of equation (2) , we are enabled to find the temperature corresponding to any pressure since s is kept constant during adiabatic expansion. Then substituting these values in the characteristic equation (1), the corresponding values of the volumes, v, may be determined. However this is a long process as it involves the solution of the transcendental equation (2). It is evident that if an exponential equation relation between pressure and volume of superheated steam could be found similar to that of a perfect gas, namely, $pv^n = C$ or some one similar to this, the labors of calculating volumes and work done during adiabatic expansion would be materially decreased. It is the purpose of this investigation to derive this relation.

Equation (3) was taken for this investigation. Eight

values of p and T were substituted in equation (3) and values of s ranging from 1.60 to 2.00 were obtained. The values of p and T were so chosen as to get nearly equidistant values of s, namely, $s = 1.60$, $s = 1.65$, $s = 1.70$ and so forth. Keeping s constant as found, values of p ranging as follows , 300, 200, 150, 100, 75, 50, 30, 15, 10, 5, 2.5, and 1, were substituted in this same equation and corresponding values of T were obtained.

The method employed in the solution of the transcendental equation to get values of T was as follows: Equation (3) was divided into two parts, namely,

$$Y = 0.8451 \log T + 0.0001\, T \quad \ldots\ldots\ldots\ldots\ldots (4).$$

$$Y = s + 0.2547 \log p + 0.3958 + \frac{C'}{T^6} \quad \ldots\ldots\ldots\ldots (5).$$

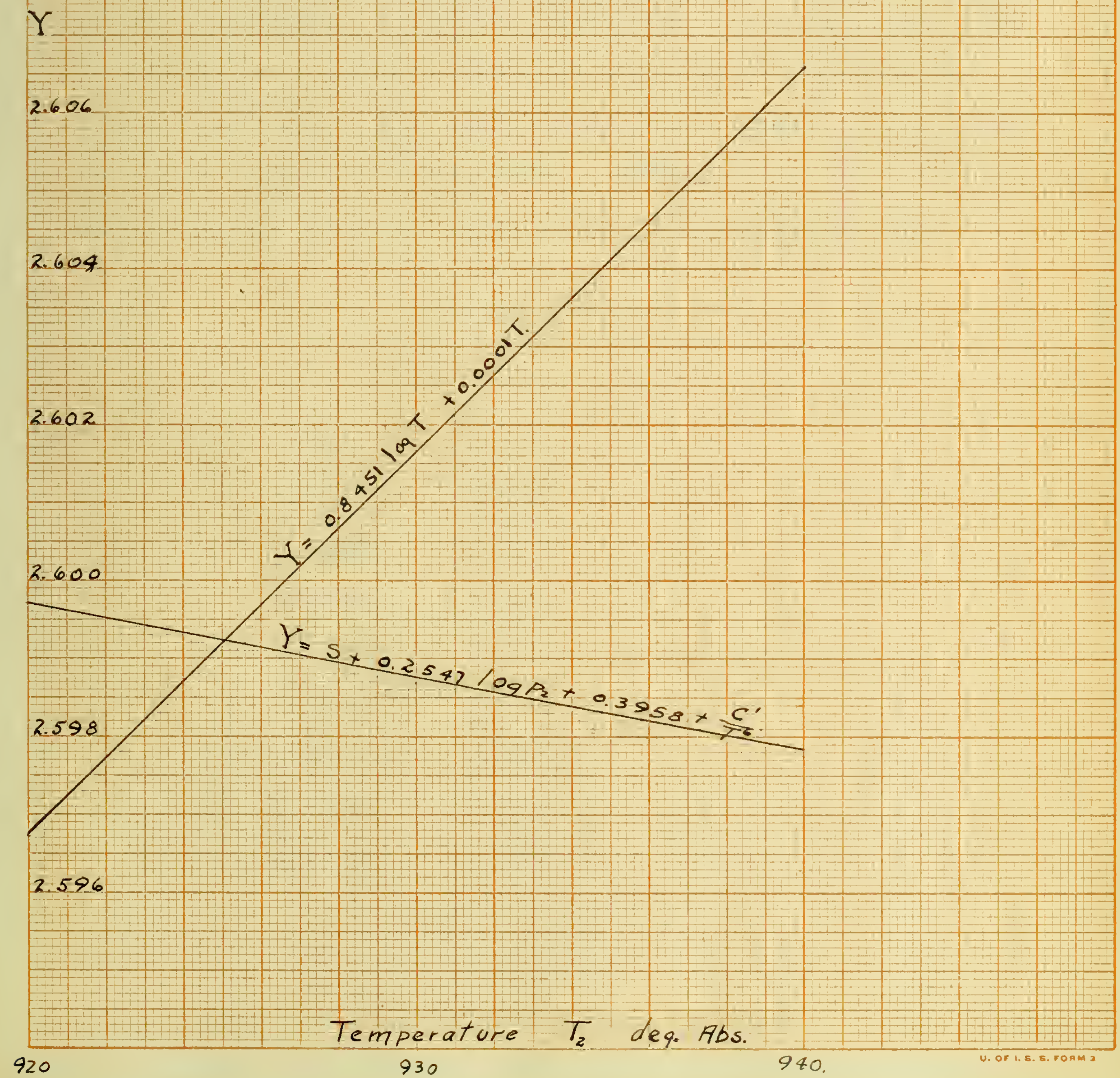
in which C' had a definite value for each pressure. Then values of T were substituted in equations (4) and (5) and values of Y were obtained. The corresponding values of T and Y of the two equations were plotted and the intersection of the two curves gave the value of T which satisfied both parts and hence the whole equation (3). A sample calculation of this solution is given on page 5.

Having corresponding values of p and T, these were substituted in the characteristic equation (1) and values of v were obtained. Now with values of p and v on an

Solution of Equation

$$S = 0.8451 \log T + 0.0001T - 0.2547 \log P_2 - P_2(1 - 0.0003P_2)\frac{C}{T^6} - 0.3958.$$

for $S = 1.60236$ $P_1 = 300.$ $P_2 = 200$ $T_1 = 1015°$ $\underline{T_2 = 925.1}$



adiabatic it became possible to determine a relation between them. A trial attempt to determine the value of n in the expression $pv^n = C$ revealed the fact that an additive constant must be used and hence the form $p(v + k)^n = C$ became necessary. In solving for each entropy to satisfy this law it was found that k varied from 0.15 at $s = 1.60$ to 1.4 at $s = 2.00$. An average value of $k = 0.4$ was taken after it was found that this value gave an equal distribution of error at both extremes. With this value of k, it was found that n varied from 1.499 to 1.320 in order to satisfy the law $p(v + 0.4)^n = C$. The method used was to make $\log p + n \log (v + 0.4)$ equal to a constant. Values of n for corresponding entropies are given in table I and are plotted on page 7.

IV. Results.

TABLE I.

Entropy.	n.
1.60236	1.449
1.65488	1.413
1.70546	1.386
1.75706	1.372
1.80435	1.354
1.85835	1.338
1.90560	1.330
2.00541	1.320

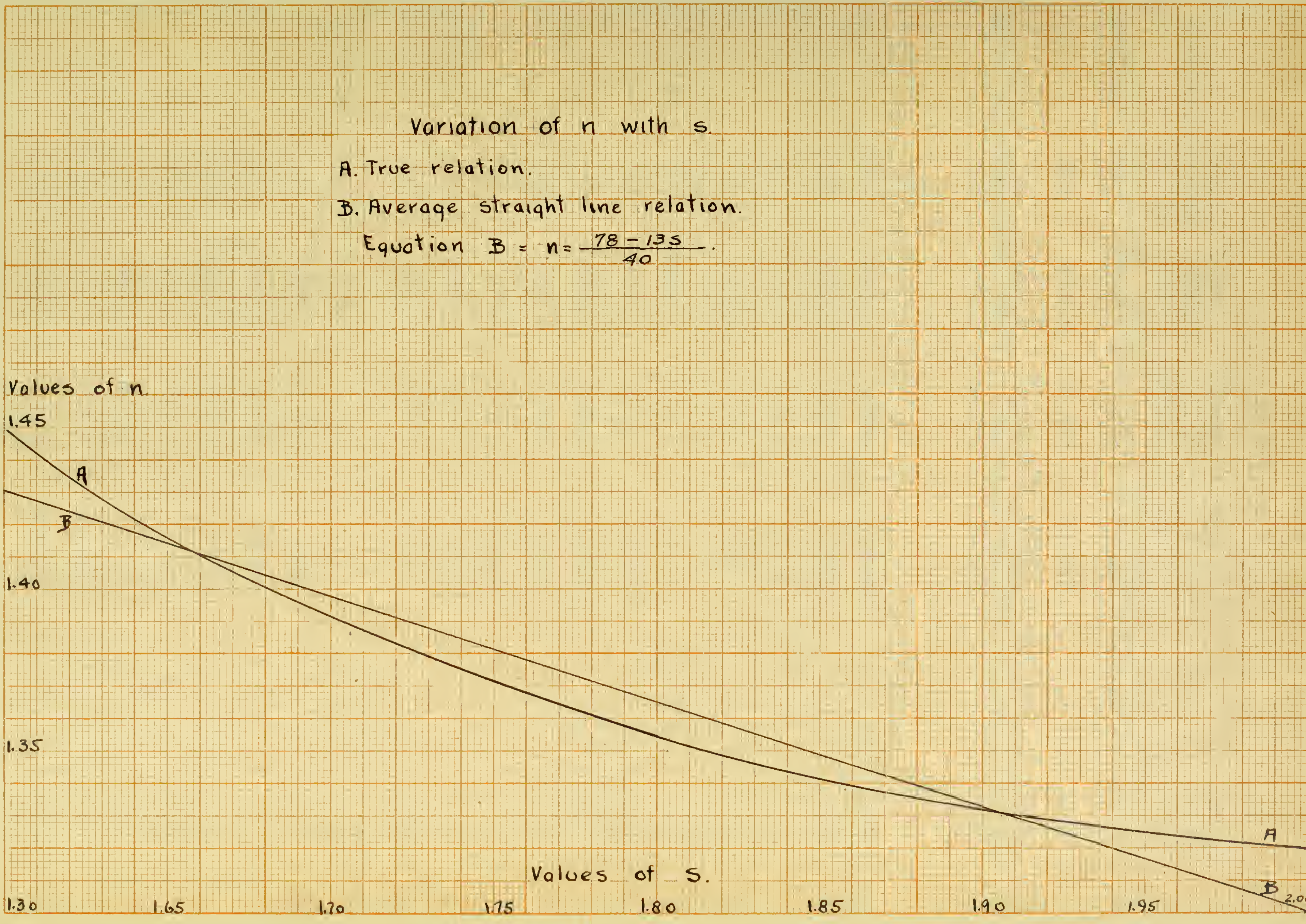

Variation of n with s.
A. True relation.
B. Average straight line relation.
Equation B = n = $\frac{78 - 13s}{40}$.
Values of n.
1.45
1.40
1.35
A
B
Values of S.
1.30
1.65
1.70
1.75
1.80
1.85
1.90
1.95
2.00

TABLE II.

Entropy	Press. lb. per sq. in.	Temp. deg. abs.	Volumes in cu. ft. Calculated	Approx.	n	Error per cent.
1.60236	300	1015.0	1.872	---	1.430	----
	200	925.1	2.587	2.617		1.16
	150	865.6	3.243	3.289		1.42
	100	789.1	4.451	4.499		1.10
1.65488	300	1120.0	2.102	-----	1.412	----
	200	1021.0	2.904	2.934		1.03
	150	955.4	3.656	3.685		1.26
	100	869.7	4.996	5.048		1.04
	75	816.8	6.271	6.287		0.26
1.70546	300	1235.0	2.343	----	1.396	----
	200	1127.0	3.240	3.269		0.89
	150	1055.2	4.064	4.105		1.01
	100	960.7	5.579	5.629		1.12
	75	902.8	6.909	7.016		1.55
	50	816.2	9.517	9.513		0.04
	30	720.5	13.997	13.891		0.72
1.75706	300	1365.0	2.611	-----	1.378	-----
	200	1248.2	3.613	3.637		0.67
	150	1169.6	4.527	4.580		1.17
	100	1066.4	6.236	6.233		0.05
	75	1003.2	7.843	7.855		0.06
	50	906.0	10.646	10.536		1.04
	30	801.4	15.710	15.660		0.32
	15	662.3	25.894	26.894		0.91

TABLE II. (Con't).

Entropy	Press. lb. per sq. in.	Temp. deg. abs.	Volumes in cu. ft. Calculated	Volumes in cu. ft. Approx.	n	Error per cent.
1.80435	300	1495.0	2.872	----	1.364	---
	200	1369.7	3.983	4.006		0.58
	150	1285.3	5.006	5.043		0.74
	100	1173.6	6.890	7.960		1.01
	75	1105.5	8.677	8.676		0.01
	50	999.7	11.795	11.871		0.65
	30	885.4	17.440	17.501		0.35
	15	747.9	29.474	29.515		0.14
	10	676.5	39.966	39.860		0.34
1.85835	200	1520.0	4.436	----	1.346	----
	150	1429.0	5.585	5.586		0.02
	100	1307.6	7.702	7.682		0.26
	75	1233.8	9.711	9.635		0.78
	50	1127.9	13.317	13.136		1.36
	30	992.4	19.609	19.440		0.89
	15	840.5	33.252	33.752		1.50
	10	761.0	45.162	45.530		1.40
	5	639.9	75.887	74.850		1.37
1.90560	100	1435.0	8.475	----	1.333	----
	75	1356.6	10.695	10.608		0.82
	50	1231.1	14.591	14.517		0.51
	30	1096.0	21.691	21.487		0.94
	15	930.7	36.889	36.429		1.25
	10	843.7	50.178	49.740		0.88

TABLE II. (Con't).

Entropy	Press. lb. per sq. in.	Temp. deg. abs.	Volumes in cu.ft. Calculated	Approx.	n	Error per cent.
1.90560	5	710.9	84.550	83.776	1.333	0.91
	2.5	596.5	141.763	140.916		0.60
2.00541	50	1500.0	17.813	-----	1.300	-----
	30	1342.5	26.618	26.402		0.80
	15	1148.7	45.616	45.467		0.33
	10	1045.6	62.296	62.463		0.27
	5	886.4	105.687	106.849		0.15
	2.5	747.4	178.136	181.733		2.02
	1.0	592.2	352.702	368.909		4.58

V. Conclusion.

It is very evident that the variation of n with s follows some definite law of the second degree. Due to the complications arising from the use of such a relation it was decided to represent this variation by means of an average straight line relation and the or plotted on page 7 was the one chosen. The equation of this line was found to be

$$n = \frac{78 - 13\,s}{40}$$

Hence we may write

$$p(v + 0.4)^{\frac{78-13s}{40}} = C$$

and

$$W = \frac{p_1(v_1 + 0.4) - p_2(v_2 + 0.4)}{\frac{78 - 13\,s}{40} - 1} \times 144$$

if p is in lb. per sq. in.

As a check upon the accuracy of the equation derived, the volumes were calculated from the relation

$$p_1(v_1 + 0.4)^n = p_2(v_2 + 0.4)^n$$

v_1 being known and n being calculated from $n = \dfrac{78 - 13\,s}{40}$.

These values and the error in percent are given in table II. This error was in a great measure due to the fact that the value of $k = 0.4$ was only correct for s in the neighborhood of 1.80. Should the correct value of k be used for each

value of entropy this error would not be present but again this would introduce further complications which would be objectionable.